Ray Tracing: the Law of Reflection, and Snell’s Law

Each of the experiments is designed to test or investigate the basic ideas of reflection and the ray-like behavior of light. The instructor will explain how to do each one on the board. You will need a ruler, a protractor, and a sharp pencil. There are five experiments – do each on a clean side of paper, with a clear heading at the top.

**Experiment 1 Test the Law of Reflection**
Set up the light box and mirror so that the incident angle is 20° or more. Use a sharp pencil to trace the outline of the mirror, and to carefully mark the center of the light beams at two well-separated points on each beam. Put circles around the points so they are visible after the rays are drawn. Carefully construct the normal using the protractor. Your partner should do a different angle from yours on a separate sheet of paper.

As soon as you have taken your data, please turn the light boxes off so they can cool down.

On the same page as the ray diagram:

i) hand-draw the following table to summarize the results for you and your partner:

<table>
<thead>
<tr>
<th>name:</th>
<th>θ(_{\text{incident}})</th>
<th>θ(_{\text{reflected}})</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Answer the following questions (also on the page with the ray diagram)

ii) Where does the reflection for your mirror appear to take place: at the front surface of the mirror, at the back surface, or somewhere between the two?

iii) discuss possible sources of experimental discrepancies between your results and the law of reflection.

**Experiment 2 Convex spherical mirror**
Find the focal length of the convex spherical (ie. circular) mirror by construction (no light rays)…

i) Place the mirror near one corner on a clean page, and carefully trace the outer edge. Then rotate the mirror within the traced curve so as to extend the circle. Continue until a full circle has been traced.

ii) Use a ruler to draw a diameter line from the one side to the other. If your line does not appear to be at the widest possible part of the circle, do it again at a different angle. Measure the length of this diameter, and write it down on the diagram: D= _____, using cm or mm. Also include the radius: R=____, and the focal length \( f_{\text{constr}}=____ \).

Sign convention: the focal length for a convex mirror is negative.
Test the law of reflection on this convex mirror surface…

i) Position the mirror at another corner of the same page. Use the light box with the mask for three parallel rays and set up a reflection from the outer surface of the circular mirror. Trace the mirror surface.

ii) The middle ray needs to be a principal ray: one that reflects directly back along itself. (Later, when we consider lenses, principal rays will be ones that pass through the center of the lens in a perfectly straight line.) Do the alignment as carefully as you can, since it will affect the accuracy of your results. This type of alignment is important in all optical systems.

iii) Use a sharp pencil to mark well-displaced points on the principal ray, and circle them as before.

iv) Also mark the one ray next to the principal ray, and its reflection. For accuracy, as always, the points you mark should be as separated as possible. However, don’t pick a point that is so far off that you can’t accurately find the center of the light ray.

v) You need the normal to measure the incident and reflected angles. It is a line from the center \( C \) of the circular mirror through the reflection point, shown dashed on the diagram below. To find \( C \), first extend the principal ray back through the interior of the circular mirror. Then, take a ruler and mark off a distance \( R \) (measured earlier) from the outer surface \( S \). This should give the center of the circle. Use this point to construct the normal (dashed) passing through the reflection point.

vi) Use a protractor to measure the incident and reflected angles. Put the results in a table on the same page, as you did for the plane mirror.

Find the focal point and focal length of this mirror using data from these rays…

i) The focal point \( F \) is the point from which reflected parallel rays appear to have come. On the diagram, it is the intersection of the reflected ray and the principal ray. Carefully extend the reflected ray so it intersects the principal ray as shown, and mark the focal point with the letter \( F \).

ii) Measure the focal length \( f \) with a ruler. It is the distance from the mirror surface \( S \), to the focal point. On the same page, near where you gave \( f_{\text{constr}} \), indicate the experimental value of the focal length: \( f_{\text{exp}} = \) ____.
Experiment 3 Concave spherical Mirror

Find the focal length by construction…

i) In one corner of a clean page, trace out the inner surface, rotating the mirror carefully to complete a full circle.

ii) Find the diameter $D$, the radius $R$, and the focal length $f_{\text{constr}}$ of the inner concave surface. Give the results on the sheet next to the diagram: $D = \_\_\_$, $R = \_\_\_$, and $f_{\text{constr}} = \_\_\_$. 

Find the focal length by using reflected optical rays…

i) Position the mirror near a different corner of the same page. Set up the light box with the three parallel rays striking the inner surface of the circular mirror. Align the system so that the center ray is a principal ray, and carefully trace the outline of the mirror.

ii) With a sharp pencil, carefully circle points on the three incident rays, and the two reflected rays.

iii) Use a ruler to mark the rays, with their directions. Note that the principal ray has arrows in both directions.

iv) The focal point $F$ is where parallel incident rays intersect after reflection. Mark this point with the letter $F$ on the diagram.

v) Measure the experimental focal length $f_{\text{exp}}$ with a ruler. It is the distance from the surface of the mirror, $S$, to the focal point, $F$. Write your result next to where the focal length was found by construction.

vi) What is the % difference between the two focal length measurements? Show the result on the page with the diagram. Use:

$$\text{% difference} = \frac{|\text{difference}|}{\text{average}} \times 100\%$$
**Experiment 4 Refraction**

In air, light travels at speed \( c = 3.0 \times 10^8 \text{ m/s} \), which is the same as its speed in vacuum (to an excellent approximation). However, in a transparent medium such as water or glass, it slows down to a speed \( v \) that might be only two thirds of the vacuum speed. The ratio of the speed \( c \) to the speed \( v \) in a medium is called the refractive index \( n \) of the medium:

\[
    n = \frac{c}{v}
\]

In air, \( n = 1.00 \), and in common transparent media, a typical value might be \( n = 1.4 \).

When a light ray enters a medium of higher refractive index, it bends or refracts. The bending is described by Snell’s law:

\[
    n_1 \sin(\theta_i) = n_2 \sin(\theta_t)
\]

The incident and transmitted angles \( \theta_i \) and \( \theta_t \), respectively, are measured relative to the normal, shown as a dashed line on the diagram. The normal is constructed perpendicular to the surface of the block of transparent material at the point of refraction. By measuring the incident and transmitted angles, and knowing the refractive index of air, we can measure the refractive index of the material from which the block is made.

Place the rectangular block on a clean sheet of paper, and set up a single ray of light passing through the system. Since relative accuracy in measurements is always improved by measuring larger quantities, ensure that your incident angle is 35° or more. Mark points on the rays entering and leaving the block. Trace the outline of the block. Then, switch off the light box and complete the diagram. The transmitted ray inside the block can only be constructed after the intersection points of the other two rays with the block surface have been found. Use a protractor to find the normal as accurately as possible. To measure the incident and transmitted rays accurately with the protractor, you will have to extend the transmitted ray and the normal.

On the same page as the diagram, neatly show the following:

i) Values found for \( \theta_i = \) ____ and \( \theta_t = \) ____.

ii) Your calculation of \( n_2 \). Show the formula, the algebra, values substituted, and the answer.

iii) Find the speed of light in the transparent block. Show the formula used, the values substituted, and the answer with correct units (of course).
Experiment 5 Critical angle
The critical angle $\theta_c$ of a medium is the smallest incident angle at which light attempting to exit the medium is totally internally reflected. In the diagram, the transmitted ray is skimming the flat back surface of the half-moon component. So, the critical angle is found by taking the transmitted angle $\theta_t$ to be 90°. The transmitted ray does not emerge, and all the light is reflected internally.

Take a clean sheet, set up the light box and the half-moon component, and find the critical angle of the material. Make sure you mark the essential details on the page so it is easy to follow what you did. When you have found the critical angle, use Snell’s law to find the index of refraction of the material.

Notes:
i) To measure the incident angle correctly, the incident light has to enter the curved surface without any refraction. This can only be accomplished if the incident ray is a principal ray.

ii) The normal can be found using a protractor and constructing the perpendicular to the back surface.

Hand in the sheets containing the diagrams, calculations, and results for the five experiments. Make sure each has a title, your name, and make sure that they are in the same order as in this handout. Points will be awarded for neatness of diagrams, as well as accuracy and completeness.